

Recommendations for Setting Biological Goals: Natural-Origin Chinook & Steelhead

Panel Interpretation of Charge:

- How should we evaluate status and trends and population-level responses of Chinook salmon and steelhead to flow and habitat restoration actions?
 - Inform progress towards biological goals
 - Inform adaptive management decisions
 - Cumulative rather than action-specific responses

Recommendations for Setting Biological Goals: Natural-Origin Chinook & Steelhead

Criteria for Evaluating Population Viability & Response to Actions

Density Dependence

Stock Recruitment framework

Defining productivity

Accounting for density dependence

Quantifying Benefits of Restoration Actions

Hatchery effects

Time Frame

Data Requirements & Limitations

Key Recommendations

Criteria for Measuring Population Viability and Response to Actions

Viable Salmonid Population Metrics

Abundance (natural origin)

Number of Recruits (catch & spawners)

Number of juveniles

Productivity

Smolts (juveniles) per spawner

Adult recruits per spawner (R/S)

Intrinsic (maximum) productivity at low density
(viable if $R/S > 1$)

Criteria for Measuring Population Viability and Response to Actions

Viable Salmonid Population Metrics

Diversity

Life history diversity (size, age, timing of outmigrants; adult age)

Genetic diversity

Diversity provides population stability, resilience, and persistence

Habitat diversity supports population diversity

Spatial Structure

Geographic distribution of meta-population

Reduces risk of catastrophic events/failure.

Density Dependence

Critical for population resilience at low abundance

Previously thought to be minimal in ESA-listed salmonids

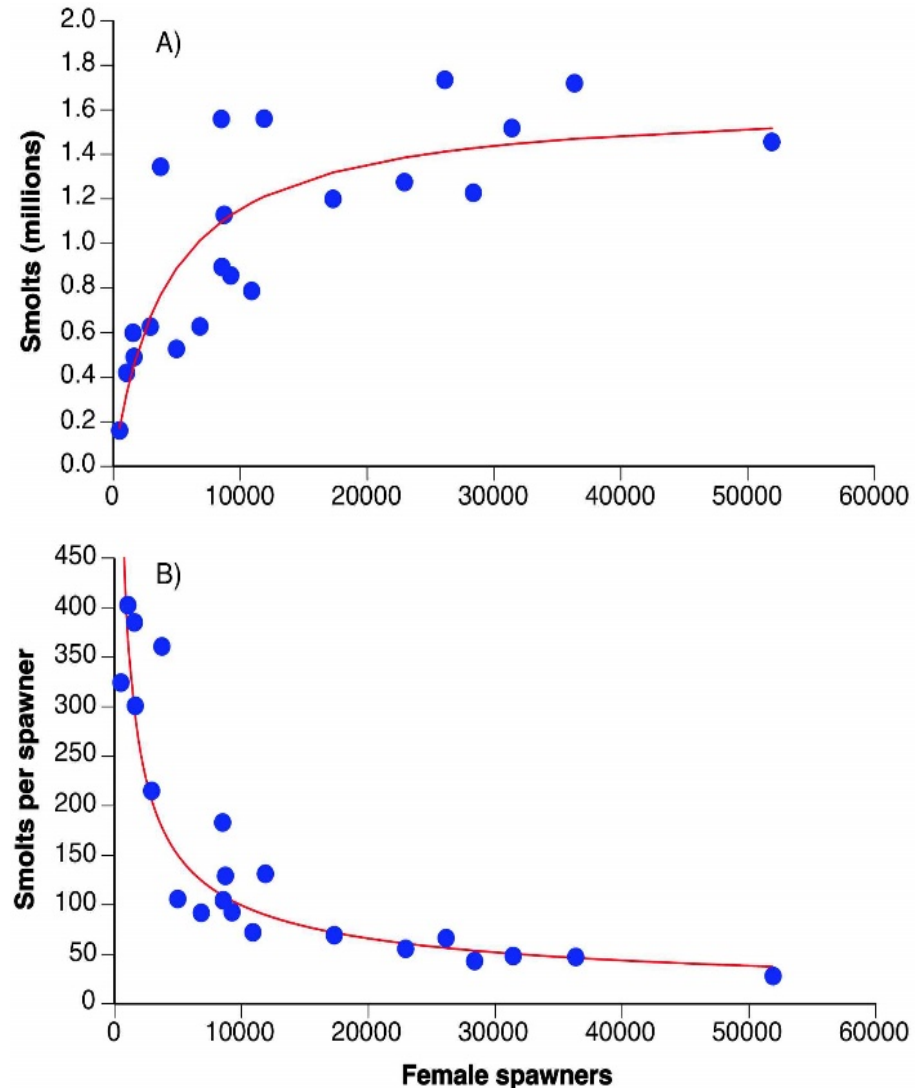
Especially important for hatchery-supplemented populations

Spawners needed to achieve viability can be estimated if SAR is known

Relationship can inform restoration actions involving capacity and productivity

Spawner-Recruit relationships reflect density dependence

Snake R spring/summer Chinook salmon



Productivity

$$R = S \cdot \pi \quad \text{or} \quad R/S = \pi$$

of Spawners

of adult returns
produced from
fish spawning in year 't'

pre-fishery abundance = Catch + Spawners

Productivity
(fecundity·survival)

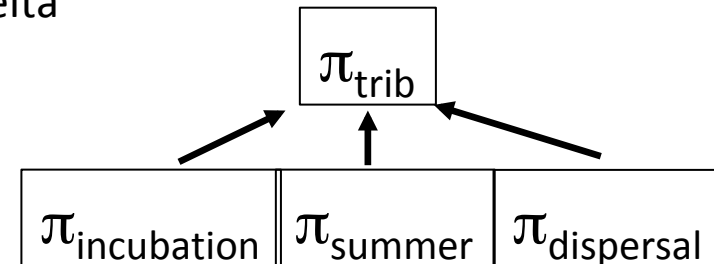
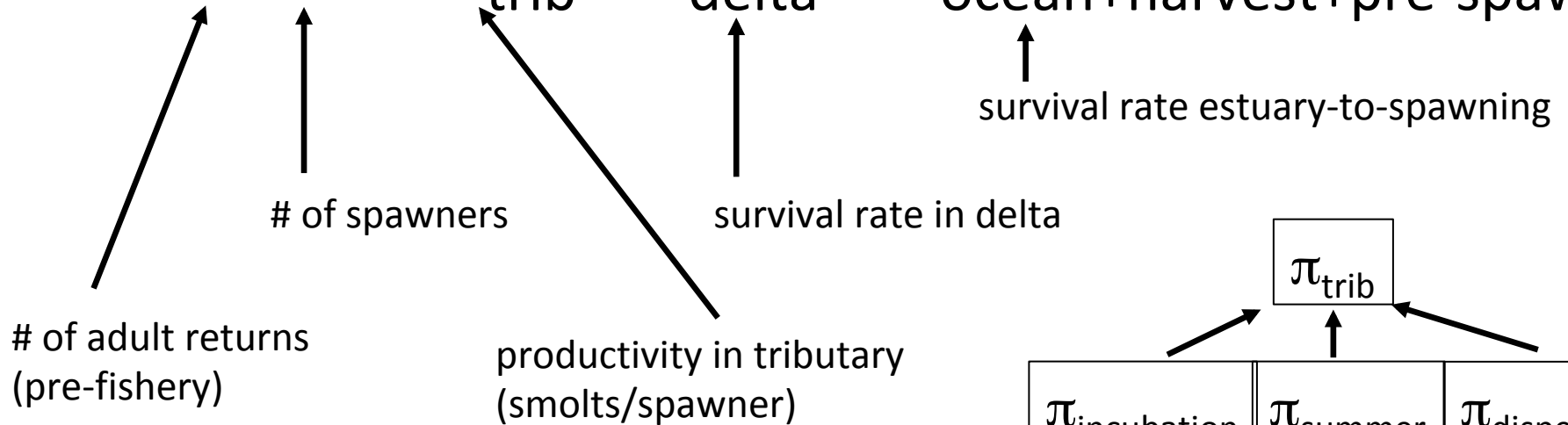
$\pi > 1$ for population to grow

Productivity (recruits/spawner)

- Determines rate of recovery
- Sustainable exploitation rate
- Determined in part by spatial and life history diversity, and determines abundance in long-term

Productivity by Life Stage

$$R/S = \pi_{\text{trib}} \cdot \pi_{\text{delta}} \cdot \pi_{\text{ocean+harvest+pre-spawn}}$$



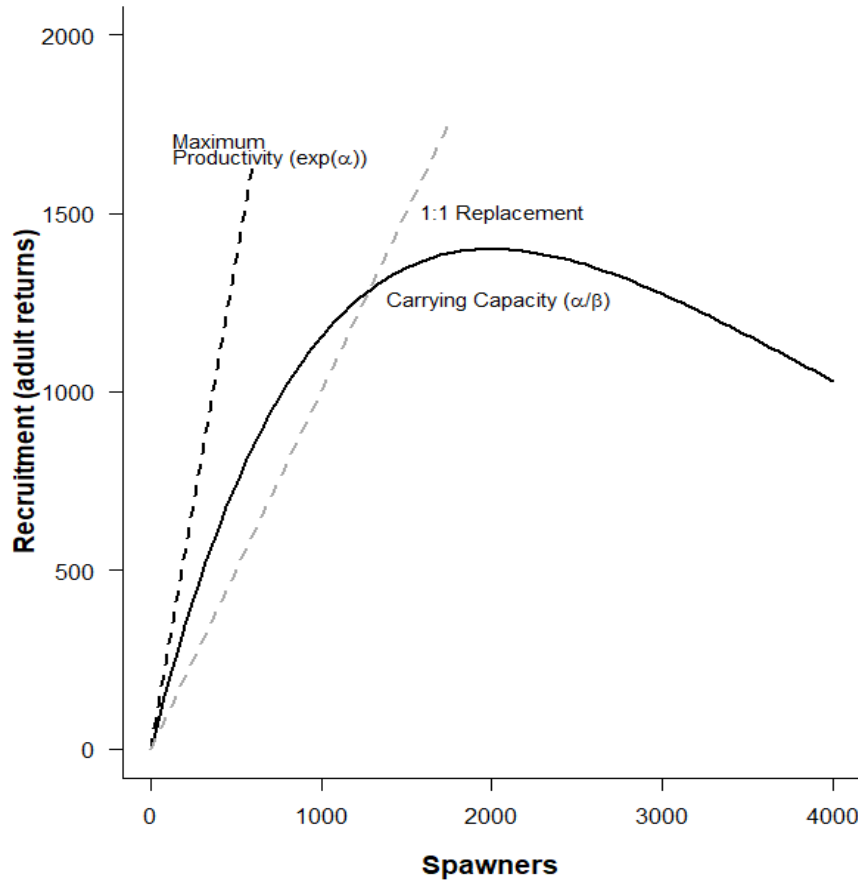
$\pi_{\text{trib}} \cdot \pi_{\text{delta}} \cdot \pi_{\text{ocean+harvest}} > 1$ for population to grow

Effect of Harvest

$$\underbrace{R/S > 1}_{\text{for population to grow}} = \pi_{\text{trib}} \cdot \pi_{\text{delta}} \cdot \pi_{\text{ocean}} \cdot \underbrace{(1-U)}_{\substack{\text{exploitation rate} \\ \downarrow \\ \text{Proportion of return} \\ \text{not harvested}}}$$

Required tributary productivity to allow population growth depends on delta and ocean survival rate, and allowable exploitation rate

Stock-Recruitment Relationships account for Density Dependence in Survival Rates



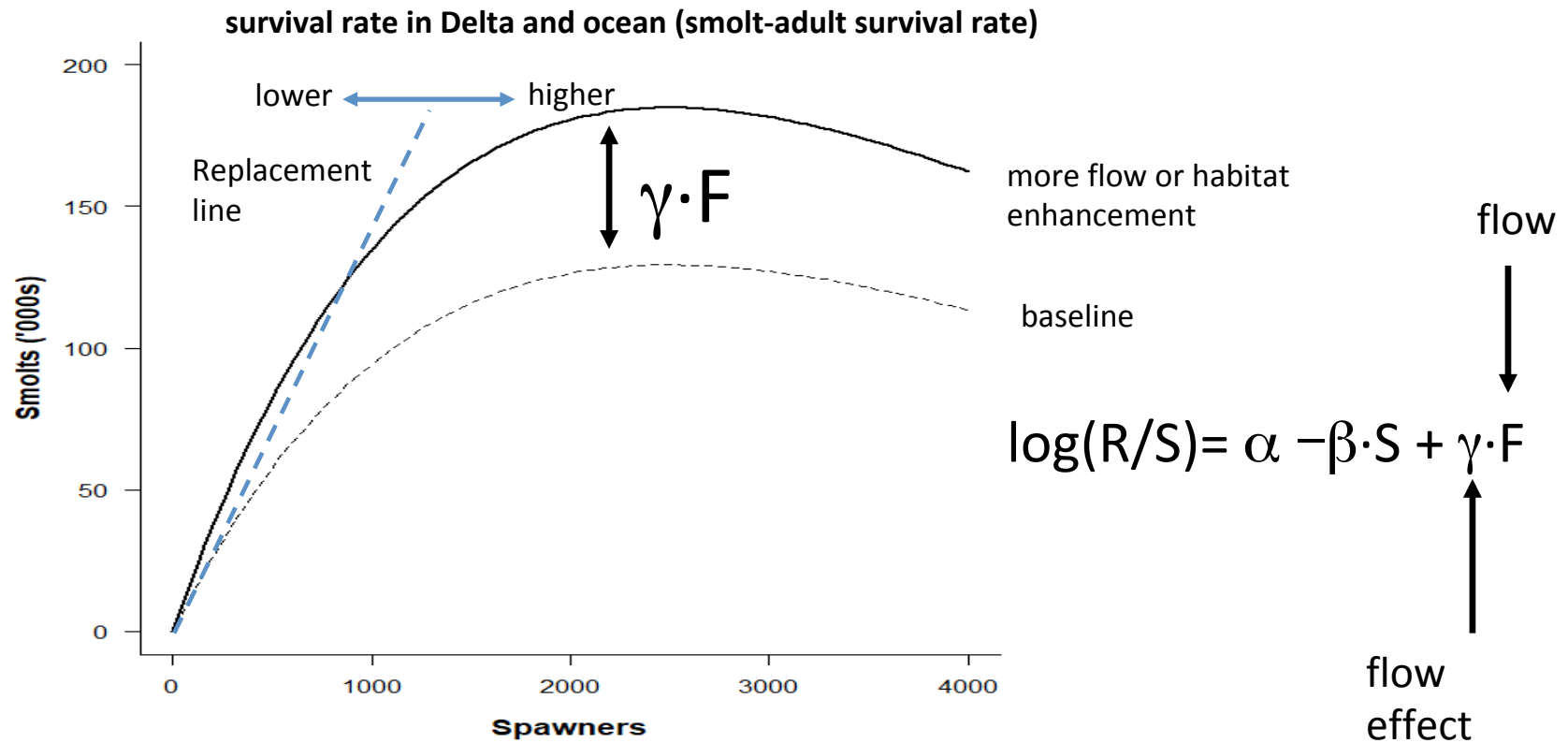
$$R = S \cdot \exp(\alpha - \beta \cdot S)$$

log of productivity
 $\exp(\alpha) = \pi$

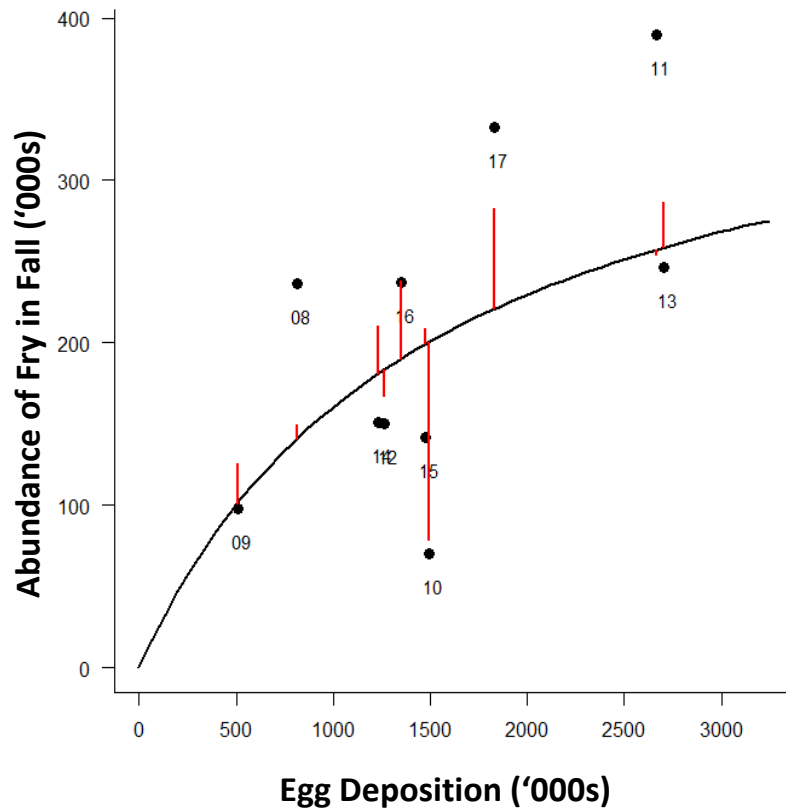
density-dependent term

$$\log(R/S) = \alpha - \beta \cdot S$$

Including Effects of Flow or Habitat on Tributary Spawner-Smolt Stock-Recruitment Relationship



Example of Tributary Stock-Recruitment Relationship



Natural (slow) decline in flow over summer (Jul-Sep_



Unstable and highly variable summer flow

$$\log(R_t/S_t) = \alpha - \beta \cdot S_t + \underbrace{\gamma \cdot F_t}_{\text{additive flow effect in year 't'}}$$

additive flow effect
in year 't'

Separation of Flow vs. Habitat Construction

What you would like to be able to do: Estimate separate flow and habitat effects

$$\log(R_t/S_t) = \alpha - \beta \cdot S_t + \underbrace{\gamma \cdot F_t}_{\text{additive flow effect in year 't'}} + \underbrace{\delta \cdot H_t}_{\text{additive habitat effect in year 't'}}$$

What you will probably be able to estimate: A combined flow-habitat effect

$$\log(R_t/S_t) = \alpha - \beta \cdot S_t + \underbrace{\gamma \cdot F_t \cdot H_t}_{\text{additive flow \& habitat effect in year 't'}}$$

Separation of Hatchery and Flow or Habitat Effects

$$R_t = S'_t \cdot \exp(\alpha - \beta \cdot S'_t + \gamma \cdot F_t)$$

$$S'_t = S \cdot (1 - \text{pHoS} \cdot \phi)$$

effective spawners

total spawners

proportion
hatchery-origin
spawners

easier to estimate

degree of reduced
reproductive potential
of hatchery-origin
spawners

hard to estimate

Factors Influencing Reliability of Flow-Habitat Effectiveness Monitoring

- Accurate and precise estimates of escapement, pHoS, smolt production, harvest, etc. will reduce observation error and make it easier to detect flow and habitat effects
- Experimental design
 - # of replicate years under each treatment
 - magnitude of treatments (% unimpaired, habitat, water year type)
 - 4-5 generations (15-20 years) to get a somewhat reliable answer based on juveniles or adult returns
 - sequencing of flow and habitat construction, changes in hatchery practices

Data Requirements

Salmon “brood table”:

Progeny produced by parent spawners

Run reconstruction needed to create brood tables for each population

Brood table data used to create spawner-recruit relationships

Example based on Kvichak sockeye salmon. Not all ages shown.

Brood Year	Parent Spawners	Number of returning progeny by age				Total progeny	Return per spawner
		Age 1.2	Age 1.3	Age 2.2	Age 2.3		
1980	22,505,268	2,539,067	1,385,037	8,291,131	364,137	12,597,313	0.6
1981	1,754,358	745,205	188,998	962,185	147,140	2,048,789	1.2
1982	1,134,840	492,725	385,823	514,201	111,122	1,509,246	1.3
1983	3,569,982	9,267,005	2,995,170	1,111,077	386,132	13,775,451	3.9
1984	10,490,670	2,578,693	1,438,443	17,559,242	1,663,051	23,287,185	2.2
1985	7,211,046	1,051,305	959,016	14,851,621	1,382,907	18,314,833	2.5
1986	1,179,322	652,917	868,159	1,539,424	1,007,436	4,114,460	3.5
1987	6,065,880	4,715,392	2,193,831	4,276,086	329,082	11,648,130	1.9
1988	4,065,216	3,035,792	1,958,434	3,698,337	453,907	9,205,714	2.3
1989	8,317,500	1,860,644	1,072,383	18,335,389	3,276,621	24,800,933	3.0
1990	6,970,020	1,635,680	890,767	22,046,414	1,626,784	26,298,686	3.8
1991	4,222,788	2,192,435	1,181,693	1,008,516	236,952	4,637,250	1.1
1992	4,725,864	651,583	300,635	751,845	162,224	1,875,603	0.4
1993	4,025,166	1,087,088	873,116	683,919	477,949	3,130,470	0.8
1994	8,355,936	2,023,631	1,062,072	3,920,261	247,105	7,303,050	0.9
1995	10,038,720	7,737,952	2,098,056	677,133	96,802	10,636,782	1.1
1996	1,450,578	547,556	1,651,818	24,302	27,656	2,260,607	1.6
1997	1,503,732	159,365	140,516	342,017	173,309	816,242	0.5
1998	2,296,074	375,942	422,187	343,819	93,558	1,254,499	0.5
1999	6,196,914	1,010,493	278,782	5,815,772	208,249	7,378,782	1.2
2000	1,827,780	1,884,652	1,264,567	742,843	367,259	4,261,658	2.3
2001	1,095,348	633,259	2,051,098	819,689	901,131	4,421,265	4.0
2002	703,884	2,456,932	1,265,247	142,426	10,246	3,881,251	5.5
2003	1,686,804	3,595,854	1,186,181	31,390	129,764	4,966,281	2.9
2004	5,500,134	4,797,865	2,931,164	2,634,426	554,819	10,918,274	2.0
2005	2,320,332	1,254,243	2,033,447	4,527,248	1,754,061	9,582,839	4.1
2006	3,068,226	3,663,815	2,701,997	1,197,115	746,641	8,319,191	2.7
2007	2,810,208	1,542,520	1,852,364	6,972,782	2,379,818	12,795,126	4.6
2008	2,757,912	2,679,158	1,930,847	1,247,528	679,005	6,577,118	2.4
2009	2,266,140	740,947	1,001,605	9,725,832	1,396,254	12,889,440	5.7
2010	4,207,410	6,053,034	5,545,200	13,231,078	679,369	NA	NA
2011	2,264,352	2,846,209	1,768,634	2,289,956	525,629	NA	NA
2012	4,164,444	7,924,673	2,820,675	423,296	NA	NA	NA
2013	2,088,576	4,001,282	NA	NA	NA	NA	NA
2014	4,458,540	NA	NA	NA	NA	NA	NA
2015	7,341,612	NA	NA	NA	NA	NA	NA
2016	4,462,728	NA	NA	NA	NA	NA	NA
2017	3,163,404	NA	NA	NA	NA	NA	NA

Data Requirements & Limitations

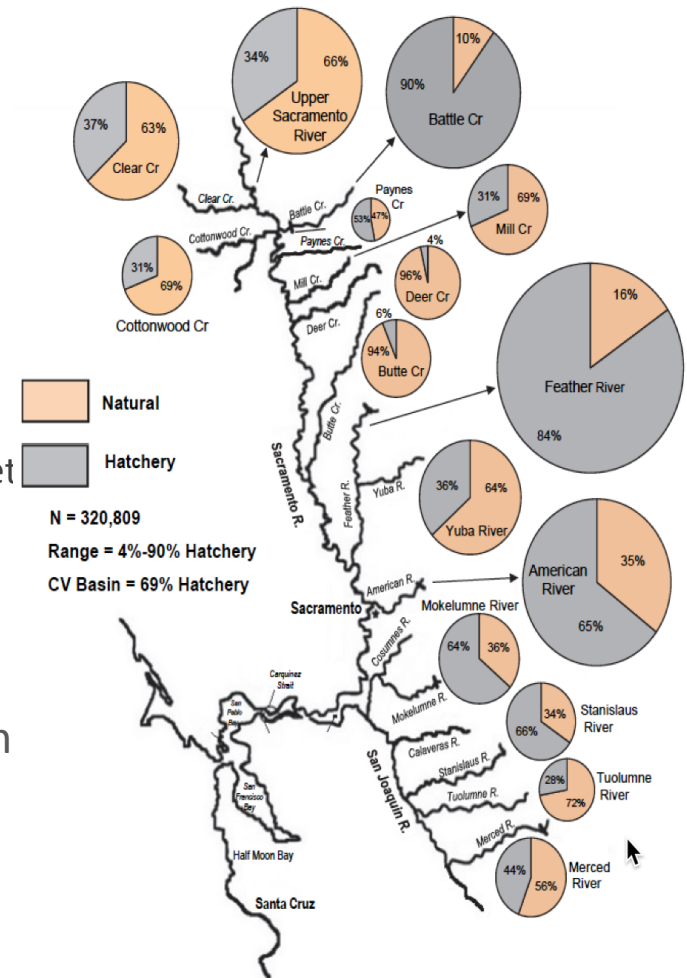
Spawning Escapement

- Total counts of male and female spawners
- Each watershed
- Each run-type (spring, fall, winter, etc.)
- GrandTab
- Age composition

pHOS (proportion of hatchery origin spawners)

- Each watershed (Palmer-Zwahlen et al. 2018, Willmes et al. 2018)
- Age composition
- Estimates for earlier years

Steelhead: data appear to be insufficient for natural origin steelhead.
Limits development of biological goals for natural-origin steelhead



Data Requirements & Limitations

Population Specific Catch Estimates

Fall, Winter, Spring Run Chinook Salmon

Commercial, sport, Tribal

Natural Origin

Hatchery Origin

Age composition

CWT-Based estimates for hatchery fish

(Barnett-Johnson et al. 2007, Kormos et al. 2012, Palmer-Zwahlen et al. 2013, 2018)

Natural origin estimates for each population?

Could use run reconstruction techniques

Data Requirements & Limitations

Tributary Outmigrant Estimates

Total population estimates

Fry, fingerling, smolts (mark-recapture)

Run-type (winter, spring, fall)

Origin (natural, hatchery)

Single population metric to estimate smolts per spawner

Juvenile size at age

Data Requirements & Limitations

Juvenile Survival through the Delta

Acoustic tag studies

(large hatchery salmon bias; proportional to wild?)

Coded-Wire-Tag studies

(smaller hatchery salmon bias)

Incorporate survival index into quantitative model (π_{deo})

Recommendations for Setting Biological Goals

Viable Salmon Population criteria (VSP)

- Abundance & productivity

 - Most intuitive

 - Develop from stock-recruit relationship

- Diversity & spatial structure

 - Stability & resilience

Recommendations for Setting Biological Goals

Productivity

Intrinsic (maximum) productivity

Spawner to smolt stage (reflects watershed actions)

productivity needed given smolt to adult survival

Spawner to adult

Viable if ≥ 1

Productivity estimated from spawner-recruitment model

Trend in intrinsic productivity estimated with state-space approach to evaluate if conditions are improving

Is population viable if all hatchery fish excluded?

Recommendations for Setting Biological Goals

Abundance

Adults or progeny produced by spawning parents

Number of spawners leading to maximum production of juveniles or future adults

Recommendations for Setting Biological Goals

Diversity

pHOS: proportion of hatchery-origin salmon on spawning grounds

Age composition

Both metrics needed to estimate productivity and abundance

Spatial Structure

Increase number of spawning populations

Recommendations for Setting Biological Goals

Action Effectiveness Monitoring:

Covariate stock-recruitment estimation approach for quantifying benefits for salmon and steelhead associated with flow, habitat improvements/restoration, and changes in pHOS

Timeframe for progress:

A few decades, depending on data quality, experimental design, and environmental variability

Timeframe could be shorter if specific life stages targeted with specific effort

Some General Conclusions

- **Ecosystem**

Develop quantitative biotic and abiotic goals separately for the estuary and tributary rivers

Both structural and functional quantitative metrics should be assessed for ecosystems

- **Other Fishes**

Evaluate both native and non-native fish species

Eight approaches are presented for other fishes that may be used to set and evaluate progress towards biological goals

- **Salmonids**

Use Viable Salmonid Population (VSP) criteria, especially productivity & abundance within stock-recruit framework

Incorporate pHOS into VSP analyses